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Head Impact Modelling Using Computer Accident Simulation Based on Cadaver Records

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Abstract

Computer simulation of specific pedestrian-car impacts was performed in order to estimate head impact velocities. These estimates will be used in physical tests to obtain force estimates, which will be correlated with actual brain damage evident in the crash victims studied. It is hoped this will lead to a better understanding of the relationship between these factors. The computer model is based upon published human joint data and the body geometry of the cadaver. One of the major unknowns and obstacles in obtaining an accurate estimate is the lack of information regarding the position of the pedestrian at the instant of impact. However, close examination of the injuries evident on the cadaver, when taken with information from eye-witness and police reports, reveal the probable position of the victim and give confidence in the results. Thus modelling based on forensic evidence in combination with physical testing can lead to accurate head impact force estimates.

Introduction

Many pedestrian accident studies have been undertaken using crash test dummies, as well as cadavers (see for example Cesari et al., 1985, Cesari & Ramet, 1975, Brun-Cassan et al., 1983, Heer and Appel, 1980). However, it is known that important changes take place in a living brain in the minutes after a severe head impact which cannot be reproduced using cadaver tests (Povlishock et al., 1996).

The NHMRC Road Accident Research Unit has conducted detailed investigations of more than 400 cases which were either fatal or resulted in a severe head injury in an attempt to obtain information on the response of the living human brain to impact to the head. In about 20 of the 200 pedestrian fatalities sufficient information is available to justify an attempt to reconstruct the collision and thereby to relate the nature and severity of the impact to the head to the nature and severity of the injury to the brain.

Computer simulations of pedestrian impacts have also been attempted in an effort to understand the mechanics involved in these accidents and hence mitigate the injuries caused to the pedestrian (e.g. Ishikawa et al., 1993, Brun-Cassan et al., 1987, Gibson et al. 1986, Van Wijk et al., 1983, Ashton et al., 1983, and Grandel et al. 1986). These studies have shown that it is possible to simulate pedestrian accidents by computer and obtain realistic body kinematics. Ishikawa et al. (1993) in particular has compared the behaviour of his model to the behaviour of cadaver experiments.

The work reported in this paper was carried out in an attempt to obtain more accurate estimates of the velocity with which the head of the pedestrian hits the car, including the angle of that impact. The computer simulation is based on MADYMO, and makes use of the actual body dimensions of the pedestrian involved, as well as the relevant dimensions of the striking vehicle.

Computer Model

The model consists of 17 rigid segments linked by kinematic joints. (See Fig 1. A & B) Although there is considerable variation between joint properties from individual to individual (see Engin, 1979, for example), it was assumed that the variation was small enough that average values would model any specific individual adequately. This generic model was created with joint properties and surface stiffness based largely upon the references in Ishikawa et al. (1993). This data was obtained from tests on human volunteers and cadavers.

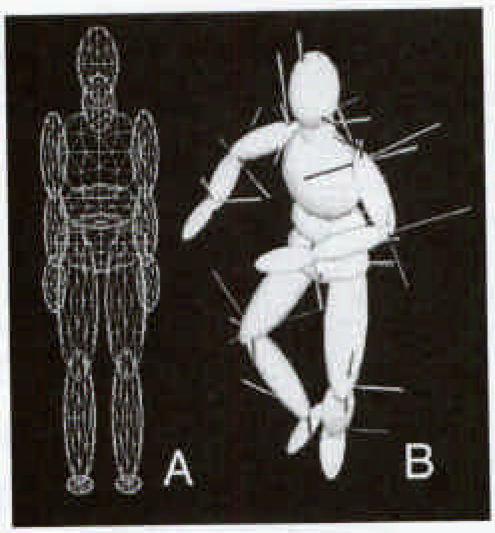


Figure 1. Seventeen-segment human model as: A) a wire frame, and B) a free floating solid body with joint co-ordinate systems visible.

The geometry, mass, moments of inertia, and centers of gravity of the individual body segments were generated using the GEBOD program (Baughman, 1983). This program generates the required data using regression equations based upon a database of human measurements, using the victim's height, weight, and sex. These measurements were made of the cadavers during the autopsy.

Some changes were made to the model developed by Ishikawa. A translational joint was superimposed on the flexion-torsion joints between the pelvis and abdomen, and between the abdomen and thorax. This was done by including another body of small mass in the model between the two different joints. This allowed for elongation of the body, due to stretching and straightening of the spine, to be represented in the simulation. This effect is not significant in impacts at low velocities, but is quite salient at higher velocities. A body elongation of up to 20% is apparent in cadaver tests with impact speeds of around 60 km/h (Cesari, c1995, Heer and Appel, 1980). A more sophisticated joint pair was used to model the neck, after the recommendations of Wismans (1995). Furthermore, a planar joint was superimposed onto the flexion-torsion joints which represented the shoulder complex. This allowed some movement in the sagittal plane of the shoulder joint, which is of particular importance in those cases where an elbow strike onto the hood of the vehicle occurs. An unyielding shoulder joint significantly alters the kinematics of the victim's body in such a situation, especially at higher impact speeds. It has been common practice to model pedestrians without arms in simulations, and even to tie back the arms of cadavers in tests, because of the complicated kinematics which they can introduce. Whilst that may be desirable in some situations, it is not appropriate if an accurate model of a real accident is sought.

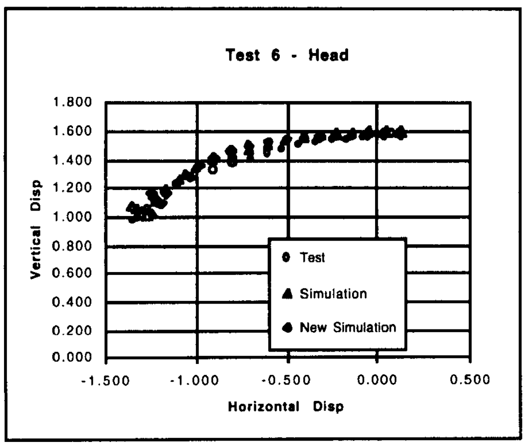
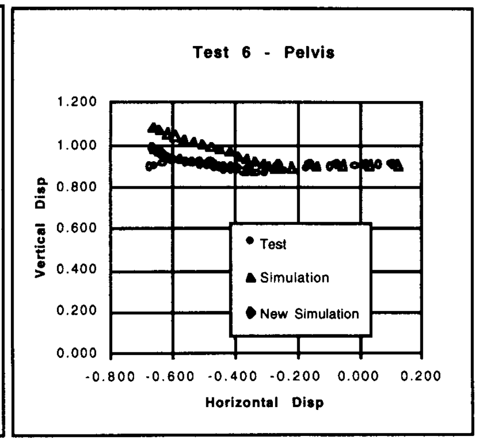


Figure 2.



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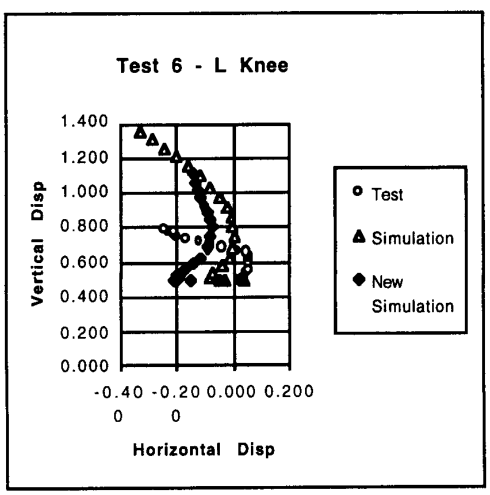

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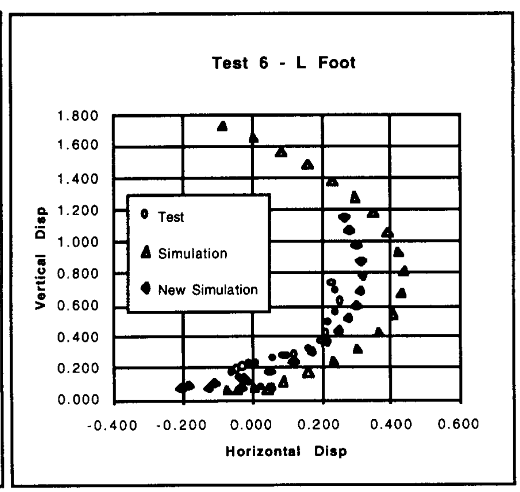

Figure 5.

Model Validation

The model was validated against actual cadaver test data provided by Ishikawa (1996), and as used in his publication (1993). An impact (Test 6 - a 32 year old male, with an impact velocity of 32 km/h) was modelled for which outline images of the cadaver at a series of time intervals during the impact were available for comparison. The comparison of the kinematics is shown graphically in Figures 2 to 5, by comparing the paths of points on the head, pelvis, knee and foot. The refined model is shown to have at least the same biofidelity as Ishikawa, using this metric. The comparison of this case to the model is complicated to some degree by the fact that several bones were fractured in the cadaver test, which were not included in either computer model.

Case Selection

Of the pedestrian fatalities documented by the NHMRC Road Accident Research Unit, a case must satisfy certain criteria to allow it to be modelled with a useful degree of accuracy. These criteria include the availability of reasonably accurate information on the impact speed of the vehicle, the alignment of the pedestrian to the front of the vehicle, the location of the impact on the head and on the vehicle, and a requirement for only one significant impact to the head. For the collision reconstruction to be of further usefulness, a detailed examination of the brain is required as well as data collected at the autopsy.

Case Reconstruction

A 17 year old female was struck from behind by a 1981 Mitsubishi Sigma GH station wagon at a speed of about 60 km/h (Case H003-88). The vehicle involved in the accident was being followed by a second vehicle which was maintaining a constant separation from the first. The driver of the following vehicle had taken notice of the speed at which he was driving (60 km/h), and that the first vehicle did not brake or accelerate before the impact.

Figure 6 shows the pattern of injuries evident on the posterior of the pedestrian involved in this accident. This pattern is consistent with an impact from behind. Lateral cuts above the heel show where the lower legs wrapped under the front of the vehicle. Heavy bruising marked with horizontal striations is evident on the back of the right knee (Figure 6, point A). These marks resemble the size and spacing of the front grille of the vehicle involved in the collision, and indicate that the right leg was the first point of contact. The bruising is slightly towards the inside of the leg, indicating that the stance was probably turned slightly to the victim's left as viewed by the approaching vehicle. Faint marks are discernible in the bruising across the buttocks of the victim marking the contact of the buttocks with the edge of the hood (indicated as point B), and are misaligned to an extent which is consistent with the hypothesis that the left foot was forward at the instant of impact. Furthermore, the amount of misalignment gives an indication of the angle between the legs at this instant, and implies a stance mid-stride at a natural walking pace. This is further corroborated by injuries to the back of the left hand (point C) which would come into contact with the front of the vehicle at an early stage during the impact.

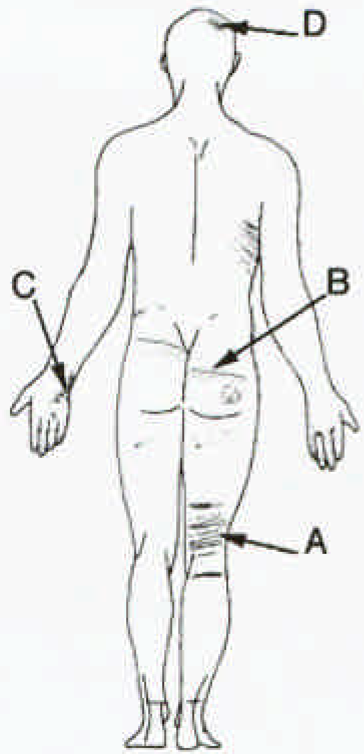

Figure 6. Relevant injuries on the posterior of the pedestrian.

Point D in Figure 6 illustrates the point of contact of the pedestrian's head with the hood of the vehicle. The location of the contusion on the right parieto-occipital region of the head may partly be due to a left elbow strike to the hood of the vehicle which rotated the body to the right. This too is consistent with the hypothesis of the victim being in a natural walking stance, turned somewhat to their left, in mid stride with their left foot forward. The resulting model illustrating the female body geometry specific to this case, and with the appropriate stance relative to the oncoming vehicle, is illustrated in Figure 7.

The geometry of the vehicle was straightforward to model using data from an appropriate service handbook. However specifying the contact interactions was much more difficult, as the impact response of the vehicle was a much greater unknown. Studies by Ishikawa et al. (1991) and Pritz (1984) into the force-deflection characteristics of various vehicle surfaces show a great deal of variation between different makes of vehicle, between different locations on a given vehicle, and even between different tests on the same location of the same vehicle. However, Ishikawa states that "the influence of the force-deformation characteristics of the vehicle on the pedestrian kinematics appears to be small as compared with the dependence on the vehicle shape".

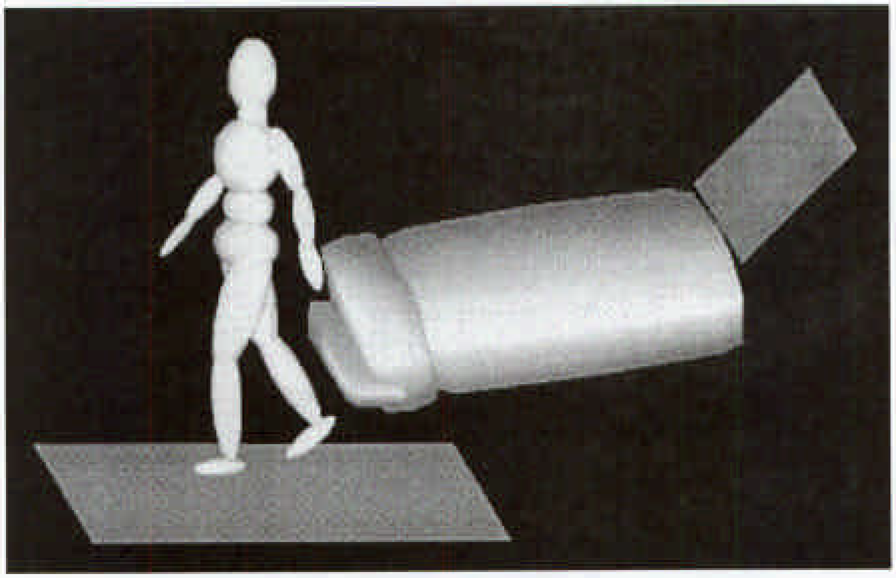

Figure 7. The final positioning of the pedestrian model with respect to the oncoming vehicle.

Results

The working simulation of case H003-88 is shown in Figure 8 as a series of stills at 20ms intervals. At t=0 the model is in the pre-impact position. The left hand is then struck by the front edge of the vehicle, and the legs wrap under the bumper. The elbow strike is clearly visible at t=60 ms, which imparts a rotation to the body, and at this point the head is travelling at a peak velocity of 21m/s (compared with the vehicle impact speed of 17 m/s). At approximately t=80 ms the head impacts the hood, and at this point the head has a velocity of approximately 10 m/s. Significant spinal elongation is evident at this stage. The body then proceeds to move up along the hood and off to the right of the vehicle.

This simulation was executed a number of times, with a variety of changes to the scenario. This was done in order to gain some insight into the sensitivity of the model to the various assumptions made. These included variations in impact speed, changes in the orientation of the pedestrian, changes in the orientation of arms, the absence of arms, and variations in the stiffness and location of the bumper. One test was done with a leg joint locked in order to obtain an upper limit to the difference that active muscle forces (which are not modelled) may have made during the impact. The Head Impact Criterion (HIC) was calculated for each case, and used as a rough benchmark to the severity of the impact. These results are presented in descending order of severity in Table 1.

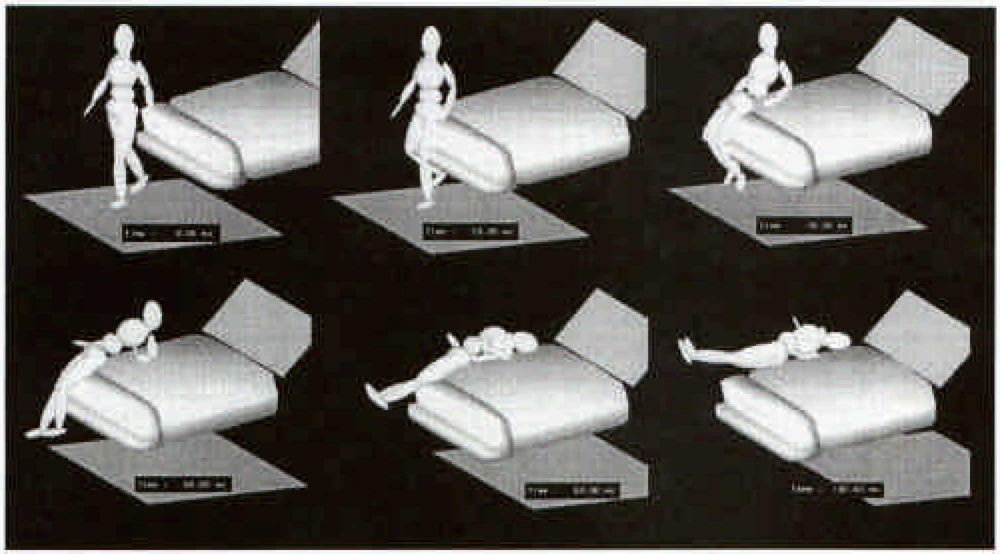

Figure 8. Computer simulation of pedestrian kinematics

Table 1. Comparison of some variables affecting the severity of head impact.

Model Variation	Bumper Type	Impact Velocity (km/h)	Orientation Angle (deg)	HIC
No Arms	Standard	60	15	4575
No Arms	Standard	50	15	3136
No Arms	Standard	50	0	2830
L Arm Bent	Standard	50	15	2732
Best Estimate	Standard	60	15	2194
Standard	Standard	50	45	1841
R Leg Locked	Standard	50	0	1805
Standard	Standard	50	0	1538
Standard	Stiff	50	15	1442
Standard	Soft	50	15	1289
Standard	Low	50	15	827
Standard	Standard	40	15	297

Discussion

It is evident that the elbow strike makes a significant difference to the severity of the head impact, and hence is an important aspect of the model. Not surprisingly the impact speed of the vehicle correlates strongly to the severity of the head impact. The orientation of the pedestrian has a moderate effect on the severity of the head impact, as does the stiffness and location of the vehicle's bumper. It appears that active muscle tension may not be a significant factor in obtaining an accurate simulation, given the small change resulting from locking the right knee joint.

Conclusions

A computer model of the pedestrian/car collision has been developed based on MADYMO and on work conducted by Ishikawa et al. (1993). The model has been validated against data obtained from pedestrian cadaver/car collisions. A sensitivity analysis indicates those parameters which need to be estimated accurately to ensure that the computer model yields meaningful results.

Acknowledgements

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DISCUSSION

PAPER: **Head Impact Modeling Using Computer Accident Simulation Based on Cadaver Records**

PRESENTER: Mike Garrett, NHMRC Road Accident Research Unit
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QUESTION: Dave Meaney, University of Pennsylvania

You didn't mention much about what the brain looked like in this example. What kind of injuries did it have?

ANSWER: Yes. That's right. I'm not a neuropathologist myself but we have rigorous brain studies of these cases and the neuropathologists have detailed records of them. They show a range of different injuries, large hematomas and different forms of external injury involved.

Q: And the second thing is, you had a bit of variability in the HIC when you changed the parameters in your model. Looking long term a little bit and maybe using these as some way of evaluating new criteria, do you have any comments as to how to resolve some of the variations that you get?

A: That's a very good question. In some ways, it is a bit like the dog chasing his tail, where do you start? I think it could be useful in evaluating different criteria. Obviously, HIC is like pulling it out of the air. I'll use that as a comparative number but I think, yes, it could be useful in examining different criterions.

Q: Guy Nusholtz, Chrysler Corporation

I may have missed it but have you checked this against any experimental data either with dummies or cadavers.

A: Yes. That's why validation graphs over there actually checked against cadaver data and also against Ishikawa's computer model. So there were three data sets there. One was my model, one was Ishikawa's model and one was actual cadaver data. And my model was obviously a re-creation of the cadaver test.

Q: How close were the time histories of the motion of the cadaver test to the model that you ran?

A: Quite reasonable. The graphs that I showed were not versus time just the vertical versus horizontal displacement.

Q: Is this the final displacement or the entire test?

A: Over time. I can show you them later.

Q: OK.

Q: Kelly Kennett, Failure Analysis

What type of joint did you use for the elbow? You mentioned that the contacts were significant. Did you use a spherical joint or a hinge joint at the elbow?

A: We used a joint allowing rotation in that direction and also a wrist rotation and that was it.

Q: So, a universal joint. Did you find that you had any problems with numerical ringing, if you will, from not having any translational cushion in that joint. I think the elbow strike's going to be quite hard and to transmit those axial forces directly into the humerus of the dummy, we've had problems with numerical ringing in that regard.

A: Yes. That's right but I found that the use of some energy absorption in the shoulder would mitigate that to some extent.

Q: OK. So, you just transmit it to the clavicle joint and then damped it out there.

A: Yes.

Q: Thank you.

Q: Frank Pintar, Medical College of Wisconsin

Have you done many of the simulations of the actual pedestrian accidents?

A: Just this one so far that's been completed because it's the best one, obviously.

Q: How detailed are you trying to simulate? If you see three dents on the hood of the car, are you going to try to simulate all of those dents. Where does your simulation stop in terms of trying to reproduce what the crash said?

A: That's a good question. It stops at the point when that particular dent doesn't look relevant to the kinematics of the body. If we can match up the elbow to the dent in the car, then we're looking at actually, in time, doing that as well and having, not just matching up the initial conditions and the frontal conditions but some of the conditions in between. But, obviously, it's nearly impossible to match up all of the damage on the body and all of the damage on the car. There is just not enough information so we're just picking out the aspects that we deem relevant.

Q: If you have multiple dents on the hood, are you making a guess as to what is a head dent versus what is an elbow dent?

A: Usually the difference between a head dent and elbow dent is very clear. For a head dent, there is usually hair left at the site, and the elbow dent is in the position that you would imagine on the bonnet so that's not really a problem.

Q: Thank you, Mike.